Speech sound development in typically developing 2-7-year-old Dutch-speaking children

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Running head: TYPICAL SPEECH SOUND DEVELOPMENT IN DUTCH CHILDREN

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Declaration of interest: The authors have no conflicts of interest to declare.

Abstract

Background: Dutch is a West-Germanic language spoken natively by around 24 million speakers. Although studies on typical Dutch speech sound development have been conducted, norms for phonetic and phonological characteristics of typical development in a large sample with a sufficient age range are lacking.

Aim: To give a detailed description of the speech sound development of typically developing Dutch-speaking children from 2 to 7 years.

Methods & Procedures: A total of 1,503 typically developing children evenly distributed across the age range of 2;0-6;11 years participated in this normative cross-sectional study. The picture-naming task of the Computer Articulation Instrument (CAI) was used to collect speech samples. Speech development was described in terms of (1) percentage consonants correct-revised (PCC-R) and percentage vowels correct (PVC), (2) consonant, vowel, and syllabic structure inventories, (3) degrees of complexity (phonemic feature hierarchy) and (4) phonological processes.

Outcomes & Results: A two-way mixed ANOVA confirmed a significant increase in the number of PCC-R and PVC between the ages of 2;0 and 6;11 years ($p < .001$). The consonant inventory was found to be complete at 3;7 years of age for the syllable-initial consonants, with the exception of the voiced fricatives /v/ and /z/, and the liquid /r/. All syllable-final consonants were acquired before the age of 4;4 years. At the age of 3;4 years, all children had acquired a complete vowel inventory and at the age of 4;7 years they produced most syllable structures correctly, albeit that the syllable structure CCVCC was still developing. All phonological contrasts were produced correctly at 3;8 years of age. Children in the younger age groups used more phonological simplification processes than the older children and by

the age of 4;4 years, all had disappeared, except for the initial cluster reduction from three to two consonants and the final cluster reduction from two to one consonant.

Conclusions & Implications: This paper describes a large normative cross-sectional study of Dutch speech sound development which, in clinical practice, can help Dutch speech language pathologists to differentiate children with delayed or disordered speech development from typically developing children.

What this paper adds

What is already known on this subject

In recent years, many studies have been conducted worldwide to investigate speech sound development in different languages, including several that explored the typical speech sound development of Dutch-speaking children, but none of these latter studies explored both phonetic and phonological progress within a ~~sufficiently wide~~comprehensive age range and a ~~sufficiently~~ large sample that is representative of the Dutch population.

What this study adds

This study serves to fill this gap by providing normative cross-sectional results obtained in 1,503 typically developing Dutch-speaking children aged between 2;0 and 6;11 years on informative parameters of speech development: PCC-R and PVC, consonant, vowel and syllabic structure inventories, degrees of complexity (phonemic feature hierarchy), and phonological simplification processes.

Clinical implications of this study

The detailed description of typical Dutch speech sound development provides speech language pathologists with pertinent information to determine whether a child's speech development progresses typically or is delayed or disordered.

Introduction

Typical speech sound development can be described as the acquisition of individual speech sounds and the organization of these speech sounds into speech patterns, encompassing both the phonetic (i.e. articulatory) and the phonological (i.e. phonemic) development. The term 'phonetic' refers to speech sound production, that is, articulatory skills, whereas the term 'phonemic' refers to speech sound use and function, and thus the organization of the speech sound system (Dodd, 2003). Speech sound production ~~or articulation~~ requires physiological movements to be made such that speech sounds can be recognized, in other words, movements that cause the production of the main features of recognizable sounds (place, manner, voice). In the process of phonetic acquisition, a distinction can be made between phonetic development prior to word learning and phonetic development in words (Winitz, 1969), where the first process has a physiological basis in that the child learns sounds falling within and outside the context of its ambient language. The phonetic development in words, however, comprises the acquisition of movements by which the relevant features of place, manner, and voice can be produced in a continuous phonetic context, and may be less of a physiological process in the sense that it involves a stable sound-meaning relationship (Winitz, 1969). ~~Young children with typically developing speech show sometimes distortions of sounds (Shriberg et al., 1997) that reflect an imprecise production of targeted sounds (e.g. dentalization or lateralization of the /s/, or labialization of the /r/) but with a correct phoneme selection. However, in words or in context, it cannot be distinguished whether distortions are of a phonetic or a phonological origin (Namasivayam et al., 2020).~~ Phonological development is characterized by the increase of phonological contrasts and the decrease of simplification processes. In clinical descriptions, the systematic differences between adult target sounds and children's realizations are described in terms of simplification processes, which can be defined as typical error patterns children produce during speech development. These simplifications involve substitution processes, where one sound is systematically substituted for another sound, assimilation processes, when a sound becomes the same or similar to another sound in the word, or syllable structure processes that affect the syllabic structure of a word. Simplification processes occur as the result of natural limitations and capacities of human speech production and perception (Dodd et al., 2003), where children try to solve these limitations by approaching the problematic target sounds or sound sequences of the target adult word with sounds that are already incorporated in their phonological system (Beers, 1995).

One of the theoretical approaches that explains the intertwinement of phonetic and phonological development is the Articulatory Phonology model (Namasivayam et al., 2020). This model describes a perspective that is based on the notion of an articulatory "gesture" that serves as a unit of phonological contrast and characterization of the resulting articulatory movements. Following this model, measuring speech in words or context involves both phonetics and phonology. Consistent production of a speech sound in context, indicates both an articulatory (phonetic) and phonological mastery of this speech sound.

A phonetic inventory of speech sounds in words catalogues those speech sounds that a child can produce in initial, medial, and final positions in syllables or words. Over and above such a phonetic inventory, one can conduct a phonological analysis, where error patterns are identified that characterize the mismatches between a child's production and adult target form in terms of simplification processes. A hierarchical analysis in terms of contrastive features (e.g., /p/ vs. /k/ or /p/ vs. /b/) provides indications regarding the child's organization of its phonological system, with, among other features, [dorsal] contrasts being required to distinguish /k/ from /p/ and [voice] to distinguish /p/ and /b/ (Ingram and

Ingram, 2001). This phonological inventory thus describes the system of contrasts a child can produce.

In recent years, many studies have been carried out to investigate typical speech sound development in different languages, among which are Putonghua (Modern Standard Chinese) (Hua and Dodd, 2000), British English (Dodd et al., 2003), Maltese (Grech and Dodd, 2008), Québécois French (MacLeod et al., 2011), isiXhosa (Maphalala et al., 2014), Malay (Phoon et al., 2014), Swahili (Gangji et al., 2015), Setswana (Mahura and Pascoe, 2016), Haitian Creole (Archer et al., 2017), Danish (Clausen and Fox-Boyer, 2017), South African English (Pascoe et al., 2018), and Italian (Tresoldi et al., 2018). Providing a cross-linguistic review of children's consonant acquisition, McLeod and Crowe (2018) concluded that in all languages five-year-old children have acquired most consonants, with individual languages differing only in the specific consonants that have not yet been mastered at that age.

Dutch phonetics and phonology

A range of studies have examined the typical speech sound development of Dutch-speaking children (Beers, 1995; Fikkert, 1994; Jongstra, 2003; Levelt, 1994; Levelt et al.; 2000, Priester and Goorhuis-Brouwer, 2013; Stes, 1977; Van den Berg et al., 2017). Dutch is a West-Germanic language and the majority language in the Netherlands and parts of Belgium, as well as in Suriname, Aruba and the Dutch Antilles. It is spoken natively by around 24 million speakers (Rys et al., 2017), with 16% speaking more than one other language, which mainly includes English, French, German, and Frisian (Fernhout et al., 2011). Of note here is that Dutch children typically learn English from the age of 10 years. English has long been a compulsory subject in all types of Dutch secondary education and since 1986 in the two final years of primary education.

The 19 consonants of Dutch and four additional consonants in parentheses are presented in Table 1. All consonants can occur in syllable-initial position, except for /ŋ/. Any consonant can occur in word-final position, except for voiced plosives, voiced fricatives, and /h/. The consonants /c, ʃ, ʒ, ɲ/ only occur in loanwords and/or as allophones (e.g. *jasje* [jɑʃ-ʃə] 'jacket'. The 16 vowels in Dutch can be divided into a set of long vowels /i, y, u, e, ø, o, a/, a set of short vowels /ı, ɛ, ɔ, ʉ, ɑ/, a reduced vowel /ə/, and three diphthongs /ɑu, ɛi, ʉy/ (Mennen et al., 2006). Long vowels, diphthongs, and the schwa can occur in syllable- and word-final position, as in *knie* [kni] 'knee' and *vrij* [vrɛi] 'free', whereas short vowels cannot occur at the end of a syllable or word, e.g. *kapstok* [kɑp-stɔk] 'coat rack'. The height classification for Dutch vowels shows two high vowels /i, u/, four high mid vowels /e, ı, o ɔ/, one low mid vowel /ɛ/, and two low vowels /a, ɑ/ (Levelt, 1994). In Dutch, like in English, a syllable consists of a vowel, from zero to three consonants in syllable-initial position, and from zero to four consonants in syllable-final position ($C^{0-3}VC^{0-4}$) (Collins and Mees, 2003), e.g. *strand* [strɑnt] 'beach' and *herfst* [hɛrfst] 'autumn'.

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Insert Table 1 about here

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Typical Dutch speech sound development

One of the first studies of typical speech sound development in Dutch was performed by Stes, who, in 1977, had 480 children aged between 3 and 10 years complete a single-word-naming task. This study was focused on the phonetic acquisition of vowels, consonants, and consonant clusters, yielding a phonetic inventory of speech sounds in Dutch words.

Determining the age of acquisition (75% of the children) and age of mastery (90% of the children), he showed that all vowels were already present at the age of three years and that at around the age of four most consonants were correctly produced by 75% of the children, with an exception for /s/ and /r/. More recently, Priester and Goorhuis-Brouwer (2013) also used a picture-naming task to chart the phonetic acquisition of speech sounds in 1,035 typically developing Dutch children between the ages of 3;8 and 6;3 years. They observed that all children older than 4;3 years pronounced most sounds (single consonants and consonant clusters) correctly.

So far, only one study looked into the typical speech sound development of Dutch-speaking children in phonological terms. Besides phonetic acquisition, Beers (1995) studied the acquisition of phonological contrasts and occurrence of phonological processes in 90 children aged between 1;3 and 4;0 years using samples of spontaneous speech. The normative data from this study are still used by clinicians to determine whether a child's speech pattern is age-appropriate, delayed, or deviant. Beers (1995) analysed the order of acquisition of Dutch consonants in syllable-initial position and found that the children aged between 1;3 and 1;8 years had acquired the consonants /p/, /t/, /m/, /n/ and /j/, reflecting the use of the contrastive features 'sonorant', 'labial', and 'coronal'. Around age 1;9 and 1;11 years, children were able to produce the consonant /k/ correctly, thereby showing they had acquired the contrastive 'dorsal' feature. Between the ages of 2;0 and 2;2 years, the children acquired the contrast 'continuant', as indicated by the correct production of the continuants /s/, /x/, and /h/. Between 2;3 and 2;5 years, children were able to pronounce /b/, /f/, and /w/ correctly, indicating that the contrastive features 'front', 'round', and 'voice' had been mastered. The children aged between 2;6 and 2;8 years had learned to use the contrasts 'nasal', 'lateral', and 'rhotic', as was shown by the correct production of the liquids

/l/ and /r/. To summarize, Dutch children were able to use all contrasts correctly at 2;8 years of age. Based on this sequence of acquisition, Beers proposed a 5-level phonemic feature hierarchy, which is presented in Table 2.

Insert Table 2 about here

Exploring simplification processes in the same sample, Beers (1995) noted that typically developing Dutch children aged between 1;3 and 1;11 years commonly used the syllable structure processes of cluster reduction, final consonant deletion, weak syllable deletion, reduplication and assimilation, and the substitution processes of (de)voicing, fronting, gliding, stopping, and vocalization. Simplifications such as reduplication and final consonant deletion, and assimilation processes showed a sharp decline in their occurrence between the ages of 2;0 and 2;5 years, while the occurrence of cluster reduction and weak syllable deletion decreased between 2;6 and 3;0 years. Only the substitution process of gliding continued to be used until the age of 4;0 years.

A year earlier, Levelt (1994) had reported on the mean percentage of vowels correct (PVC) for Dutch-speaking children, finding that the high vowels /i, u/ and the low vowels /a, ɑ/ are acquired first, while the low-mid vowel /ɛ/ is mastered last. In other Dutch studies the acquisition of syllable structures was investigated (Fikkert, 1994; Levelt et al., 2000; Van den Berg et al., 2017), as well as word-initial consonant clusters (Jongstra, 2003), and place features and vowel height (Levelt, 1994). Van den Berg et al. (2017), Fikkert (1994), and Levelt et al. (2000) concluded that simple syllable types (CV, V, and CVC) appear simultaneously and before complex syllable types. In most of the children examined, onset clusters emerged before final clusters, while the order of acquisition of complex clusters was found to be variable (Jongstra, 2003; Van den Berg et al., 2017). All studies mentioned were based on spontaneous speech samples, apart from the study by Jongstra (2003), who used a picture-naming task.

Priester et al. (2011) reviewed the British-English and Dutch literature on normative data for speech sound development and found a universal trend for the two languages. In both, all vowels are mastered at three years of age and most single consonants are present around the age of four, except for /s/ and /r/. A difference between English and Dutch was found in the age of acquisition of consonant clusters. In English, most consonant clusters were mastered by the age of five (Dodd et al., 2003), whereas in Dutch most clusters were not acquired until the age of six, with the development possibly even continuing up to the age of 10 (Stes, 1977). Priester et al. (2011) suggest that these differences may be caused by language differences, Stes' data (1977) being outdated, and/or differences in the analysis methods used. ~~Nota bene~~Of note, Dodd et al.'s (2003) was a broad description of the development of consonant clusters, while that of Stes' (1977) was based on a detailed analysis. However, Smith (1993) showed that, although all initial consonant clusters are produced as clusters in typically developing English-speaking children by the age of 5;0 years, there may continue to be segmental errors within these clusters. Also other studies report that in English the development of consonant clusters still continues after 5;0 years of age (McLeod et al., 2001).

Thus, although multiple studies are available on the typical speech sound development of Dutch-speaking children, no recent studies have focused on both the phonetic and phonological aspects of this process in a sufficiently large sample that includes a sufficiently wide age range. All Dutch studies on the acquisition of vowels and syllable structures were conducted in small groups of children (*n* = 12 to *n* = 45) comprising young children only, with ages ranging between 6 months and 3;4 years (Fikkert, 1994; Jongstra, 2003; Levelt, 1994; Levelt et al., 2000; Van den Berg et al., 2017). The Stes (1977) and Priester and Goorhuis-Brouwer (2013) studies did have large samples, but both only reported on phonetic development, with the latter study being restricted to consonants. Furthermore, having been collected in the late 1970s, the findings Stes reports are most likely at least partly outdated. Also~~nd~~, even though Beers (1995) did describe both phonetic and phonological features, she did so on the basis of observations obtained in 90 children. Moreover, there is no research on the percentage of consonants correct (PCC) in Dutch, notably the most well-known and well-established measures used in clinical practice that is frequently cited in research literature (Fabiano-Smith, 2019; Masso et al., 2018). Accordingly, there is a clear need for norms of speech sound development for the Dutch language that are clinically-sensitive to differentiate children with delayed or disordered speech development from typically developing children (Dodd et al., 2003), where delayed speech manifests itself in error patterns that are typical of a younger chronological age and disordered speech by error patterns that are atypical of any age group in a normative sample (Dodd, 2011).

Methods of speech elicitation for the assessment of speech

There are different methods to elicit speech for assessment purposes. The studies on typical Dutch speech acquisition mentioned above used two such methods: conversational or spontaneous speech and single word naming (using a picture-naming or word-imitation task). The advantages of both techniques have been described extensively (Masterson et al., 2005; Wolk and Meisler, 1998; Morrison and Shriberg, 1992), with both methods having been shown to be useful for clinical assessments (Masterson et al., 2005; Wolk and Meisler, 1998). Conversational or spontaneous speech has the advantage of providing phonetic contexts while allowing the child's abilities to be tested in real-life, natural communication. On the other hand, spontaneous speech introduces undesired variability due to individual differences in the propensity and motivation to talk, such that the child might not perform at maximum level and, for instance, avoid problematic target sounds or sounds that are not yet firmly embedded in its phonological system. In addition, analysing spontaneous speech is time consuming. A word-naming task can thus be a more efficient way to elicit and analyse speech in children, with the target words covering all aspects of Dutch speech sound production.

The current study

With this cross-sectional study we aim to give a detailed description of the speech sound development of Dutch-speaking, typically developing children and provide normative data for use in clinical practice to differentiate children with speech sound disorders (SSDs) from children showing typical development. To ensure efficiency in our data collection and analysis, we opted for a picture-naming task to elicit speech, of which the audio recordings were evaluated, scoring the following parameters: PCC and PVC, consonant, vowel, and syllable-structure inventories, degrees of complexity (phonemic feature hierarchy), and phonological processes.

Methods

Research design

A cross-sectional design was used to identify trends of speech sound development.

Recruitment of participants

This study analyses the speech samples of the picture-naming task collected within the framework of our group's normative study of the Computer Articulation Instrument (CAI); see Van Haaften et al. (2019a) and Maassen et al. (2019) for information on the data-collection method and sample characteristics. The children were aged between 2;0 and 6;11 years and drawn from 47 nurseries and 71 elementary schools located in four different regions of the Netherlands. The nurseries and schools were sent a letter explaining the purpose of the study and inviting them to participate. All parents of the children in the participating nurseries and schools were handed an information letter. After the signed parental consent form had been received, the child was included in the study. The 4- to 7-year-old children were recruited between January 2008 and December 2014, and the 2- to 4 year-olds from March 2011 to April 2015.

Participants

Of the total of 1,524 children participating in the CAI normative study, 1,503 children completed the picture-naming task. We opted for the age range of 2;0 and 6;11 because during this period speech sound development is expected to be completed. The minimum age of 2;0 years was chosen because at that age a child's vocabulary and attention span is sufficient for a picture-naming task. Stratifying for age, 14 groups were created with a range of 4 months for children aged 2;0-5;11 years and a range of 6 months for those aged 6;0-6;11 years. As is recommended for the assessment of speech language development

(Andersson, 2005), all age groups contained more than 100 children, except for the youngest age group (*n* = 72) and the group of 4;0-4;3-year-olds (*n* = 99).

The criteria for inclusion were: no hearing loss and Dutch being the spoken language at the nursery or primary school. The parents and teachers of eligible children were asked to complete a questionnaire about the children's development. Another language than Dutch (e.g. Turkish, Arabic, or German) was spoken at home in 3.9% (*n* = 59) of the participants. To ensure the normative sample was representative of the Dutch population, we also included children with a history of speech and language difficulties (*n* = 32, 2.1%). The sample was representative of the general Dutch population in terms of gender, geographic region, degree of urbanization, and parental socio-economic status (Van Haaften et al., 2019a). Table 3 summarizes the characteristics of the sample.

Insert Table 3 about here

Ethical considerations

The research ethics committee of the Radboud University Nijmegen Medical Centre judged that our study did not fall within the remit of the Dutch Medical Research Involving Human Subjects Act (WMO; file number: CMO 2016-2985). Therefore, the study was allowed to be carried out without approval by an accredited research ethics committee. Informed consent was obtained from all parents or legal guardians.

Materials

The speech samples recorded during the performance of the picture-naming task in the CAI study (Maassen et al., 2019) were used. The psychometric properties of this task have overall been found to be sufficient to good (Van Haaften et al., 2019a). The interrater reliability was sufficient to good, with percentages for point-to-point agreement above 95% for all measures. The construct validity of the CAI was demonstrated by the correlation of the outcomes of the CAI with age. Monotonous increases with age were found for all parameters of picture naming, such as the PCC and the PVC, and the percentages of cluster reductions and correctly produced syllable structures. Together, these results indicate that the picture-naming task of the CAI is a reliable and valid test to assess speech in typically developing Dutch children.

Our picture-naming task comprises 60 words incorporating the full repertoire of vowels, consonants, consonant clusters, and syllable structures of the Dutch language. The target words vary from simple to more complex in terms of the number of syllables, comprising 40 one-syllable words, 13 two-syllable words, 6 three-syllable words, and 1 word with four syllables (see Appendix A). The task thus assesses all Dutch phonemes in all possible syllable and word positions, except for /g/ because in Dutch this consonant only occurs in loanwords. All phonemes occur at least twice in different positions in different contexts (see Appendix B). Words were presented in a fixed order. For the 4- to 7-year-olds the complexity of words varied, while for the 2- to 4-year-olds the CVC words were presented first, followed by the words with more complex syllable structures.

Both seated in front of a computer screen, the speech language pathologist (SLP) asks the child to name the (colour) pictures that appear consecutively on the screen aloud. A pre-recorded audio prompt provided a semantic cue when the child was unable to name the picture spontaneously. When the cue did not elicit the target word, the target word was spoken by the computer, which the child then had to repeat out loud.

Procedure

The children were tested individually in a quiet room in their own nursery or primary school. The administer and child were seated side by side at a table on which a laptop computer was placed in a position comfortable for both. They both wore headsets or, if preferred, a speaker and microphone were used. All utterances were audio recorded and stored in the CAI software program.

The task was administered by 14 SLPs in the younger age groups (2-4-year olds) and in the older children (4-7-year olds) by 110 third- or fourth (final)-year SLP students working in pairs. All were trained in the administration of the CAI by the first two authors, having received precise instructions and training in the scoring procedure (phonetic transcription). Scoring was done by the same SLP(s) that had administered the test under supervision of the first two authors.

Data analysis: phonetic transcription

Each utterance of each audio recording was transcribed phonetically using the Logical International Phonetics Programs software (LIPP) (Oller and Delgado, 2000), which allows for the transcription of IPA via the traditional keyboard, along with user-designed analysis based on featural characterizations of segments. The assessors transcribed all speech recordings based on the correct target transcriptions by 'editing in' the child's production errors. They used a broad phonetic transcription in which phonetic variation (e.g. a lisp) was not represented, whereas sound distortions that resulted in a change of feature (place, manner, voice) were. The transcriptions were used to investigate:

- *PCC and PVC.* All consonants and all vowels were considered when calculating PCC and PVC, where PCC is the percentage of correctly produced consonants divided by the total number of target consonants. In this study, both common and uncommon clinical consonant distortions were scored as correct, similar to the calculation of the Percentage of Consonants Correct–Revised (PCC-R), as described by Shriberg et al. (1997), since investigating systematic distortions was not the aim of our analysis. Consistent speech sound production with or without a consistent distortion reflects both correct phonemic selection and correct phonetic production (albeit the distortion). A phonemically irrelevant consistent distortion can be diagnostically isolated from the correct phoneme selection and articulatory realization processes; the production of distorted phonemes in different contexts signifies mastery of gestures at the phonemic and articulatory level albeit the distortion itself. PVC was calculated by dividing the vowels pronounced correctly by the total number of target vowels elicited with the picture-naming task.
- *Phonetic inventory.* Applying the 75% frequency criterion, we deemed speech sounds (vowels and single-syllable initial and final consonants) to have been acquired when 75% of the children of an age group produced the targeted speech sound correctly, while a speech sound was considered to be produced correctly when a child produced the target sound ≥ 75% of the cases correctly. Like in the study of Beers (1995), this percentage was based on at least two attempts of a target sound, except for /ʒ/ in syllable-initial position as this sound only occurred once in the item list (see Appendix B for the frequency distributions of the phonological features of the

picture-naming task). The mean percentages of correct productions per speech sound (vowels and single-syllable initial consonants) were calculated.

- *Degrees of complexity.* Having studied the acquisition of contrastive features in syllable-initial position in typically developing children, Beers (1995) classified the degrees of complexity for the Dutch language (see Table 2). We used her classification system (or phonemic feature hierarchy) for the present study and performed relational analyses comparing the child's productions with the target form. A specific degree of complexity was classified as age-appropriate when the syllable-initial consonants of that complexity were, on average, correctly produced ≥ 75% of the cases by at least 75% of the children in an age group.
- *Syllable structure inventory.* A syllable structure was considered to be produced correctly when a child produced the syllable structure ≥ 75% of the cases correctly, irrespective of whether the syllable was produced correctly at the segmental level. Comparable with Gangji et al. (2015) and Clausen and Fox-Boyer (2017), we considered a syllable structure to be present in the inventory of an age group when 75% of the children produced the syllable structure correctly. Our task comprised the following syllable structures: V, CV, CVC, CCV, CVCC, CCVC, CCVCC, and CCCVC.
- *Phonological processes.* In accordance with Dodd et al. (2003), and several others (Kirk and Vigeland, 2015, Clausen and Fox-Boyer, 2017, Hua and Dodd, 2000), we classified a phonological process as age-appropriate when it fulfilled the 10% criterion, i.e. when it occurred at least 10% in at least 10% of the children within an age group. We charted both 'normal' phonological processes as described by Beers (1995) and unusual processes.

Statistical analyses

The analyses of PCC-R and PVC, phonetic inventory, degrees of complexity, syllable-structure inventory, and phonological processes consisted of a description of the data per age group.

To compare the effect of age on PCC-R and PVC and to test the hypothesis that there is a difference between PCC-R and PVC for the 14 age groups, a two-way mixed ANOVA was conducted with the percentage of correct productions as the dependent variable, type of measure as the within-subject factor with two levels (PCC-R and PVC), and age group as the between-subject factor with 14 levels (14 age groups).

Results

PCC-R and PVC

The mean scores and standard deviations of each age group for PCC-R and PVC are shown in Table 4. The mean number of both types of percentage correct scores increased with age. The results of the two-way mixed ANOVA showed there was a significant main effect of type of measure; the difference between PCC-R and PVC was significant, $F(1, 1489) = 779.54$, $p < .001$, effect size or partial $\eta^2 = .34$, with PVC being systematically higher than PCC-R. There was also a significant main effect of age group on the percentage of correct productions ($F(1, 13) = 94.83$, $p < .001$, effect size or partial $\eta^2 = .45$). In addition, there was a significant interaction between 'type of measure' and 'age group' ($F(13, 1489) = 34.89$, $p < .001$, effect size or partial $\eta^2 = .23$). Descriptive statistics demonstrated that the difference between PCC-R and PVC was larger for the younger age groups than it was for the older age groups.

Insert Table 4 about here

Phonetic inventory

Table 5 summarizes the phonetic inventory of each age group. All vowels were acquired before the age of 3;4 years. All short vowels and most of the long vowels (except /e/), and the diphthongs (except /ɑu/) were acquired at age 2;7 years. By the age of 3;7 years, 75% of the children were able to produce all the syllable-initial consonants ≥ 75% of the cases correctly, except for the voiced fricatives /v/ and /z/ and the liquid /r/. All final consonants were acquired before the age of 4;4 years.

Insert Table 5 about here

Degrees of complexity

Table 6 shows the phonemic feature hierarchy in terms of the percentages of the occurrence of the various degrees of complexity across the age groups. The results indicate that the syllable-initial consonants /p/, /t/, /m/, /j/ and /n/ of degree 1 were produced correctly at the age of 2;0 years. The children aged 2;8 years were able to produce the dorsal consonant /k/ correctly. At the age of 2;4 years, the continuants /s/, /x/ and /h/ had been acquired, and at age 2;8 years the consonants /b/, /f/ and /w/, with those of degree 5 being acquired at 3;8 years of age. This order of acquisition confirmed that the older children in our sample used more phonological contrasts than the younger children, thereby corroborating Beers' complexity model.

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Insert Table 6 about here

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Syllable-structure inventory

The results of the syllable-structure inventory are shown in Table 7. All two-year-old children had acquired the simple syllable structures CVC, CV, and V, and the more complex structures with an initial or final consonant cluster of two consonants by all 3-year-olds. Children in the 4;4-4;7 age group had acquired the syllable structure with an initial consonant cluster of three consonants (CCCVC), while the CCVCC structure was not acquired until after the age of 6;11.

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Insert Table 7 about here

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Phonological processes

The phonological processes that were observed in our normative sample are presented in Table 8. Most phonological processes are resolved after 4;3 years, except initial cluster reduction from 3 to 2 consonants, e.g. [stɪk] for [strɪk] 'bow' and final cluster reduction from 2 to 1 consonant, as in [kɑs] for [kɑst] 'closet'. Backing (e.g. [kɔŋ] for [tɔŋ] 'tongue'), nasalisation (e.g. [nɪp] for [wɪp] 'seesaw'), voicing (e.g. [zɔk] for [sɔk] 'sock'), gliding (e.g.

[bjuk] for [bruk] ‘pants’), h-sation (consonants are replaced by /h/, e.g. [hɛɪn] for [trɛɪn] ‘train’) and lateralisation (e.g. [lɑs] for [jɑs] ‘coat’) did not occur in the normative sample.

Insert Table 8 about here

Discussion

This cross-sectional study provides in-depth information on the typical speech sound development of Dutch-speaking children aged between 2;0 and 6;11 years in terms of PCC-R and PVC, the age of acquisition of consonants and vowels, while describing age-specific syllabic structure inventories, degrees of complexity (phonemic feature hierarchy), and phonological processes.

PCC-R and PVC

Consonant accuracy (PCC-R) and vowel accuracy (PVC) significantly increased with age, demonstrating a gradual progress in the children’s ability to speak the Dutch language adequately. Between the ages of 2;0 and 2;3 years, the children in our sample produced consonants with a 76.4% accuracy, while the PCC-R of the children aged 6;6 to 6;11 was 97.6%. PVC scores increased from 87.5% in the youngest to 98.6% in the oldest age group. These results are broadly comparable with the PCC and PVC findings of studies evaluating other languages (Clausen and Fox-Boyer; 2017, Gangji et al., 2015; Grech and Dodd, 2008; MacLeod et al., 2011; Maphalala et al., 2014), although the comparison is not conclusive because some of the other studies used PCC instead of PCC-R. When calculating PCC-R, both common and uncommon clinical consonant distortions are scored as correct (Shriberg et al., 1997), which results in higher scores. We found no studies that used both measures.

The PVC scores were significantly higher than the PCC-R scores, which is also typical for other languages (PVC versus PCC) (Clausen and Fox-Boyer, 2017; Dodd et al., 2003; Pascoe et al., 2018). This was expected since the phenomenon is explained by the phonetic difference between vowels and consonants, where the production of the latter sounds, and especially consonant clusters, requires more precise speech motor skills than does the production of vowels. Furthermore, even though speakers may show variation in the speech production of a specific vowel, the acoustic output of that vowel is still recognized as the same vowel (Johnson et al., 1993). As a result, the judgment of vowels is less strict than that of consonants (Howard and Heselwood, 2012).

Phonetic inventory

The phonetic inventories supported the PCC-R and PVC findings in that, as expected, the older children were able to produce more vowels and consonants correctly than their younger counterparts. All the children aged 3;4 years had acquired a complete vowel inventory. Similar results were found for the English language (Dodd et al., 2003). The consonant inventory was almost complete at age 3;7 years for the syllable-initial consonants, except for the voiced fricatives /v/ and /z/, and the liquid /r/. All syllable-final consonants were acquired before the age of 4;4 years, which is comparable with the results Stes (1977) and Priester and Goorhuis-Brouwer (2013) reported and the findings for other languages. For example, the consonant /r/ is one of the latest acquired consonants in English-speaking children (Dodd et al., 2003) and in children speaking Swahili (Gangji et al., 2015).

Like in most languages (McLeod and Crowe, 2018), nasals, plosives, and glides in syllable-initial position were acquired earlier than syllable-initial liquids and some fricatives. In syllable-final position, plosives and glides were acquired before fricatives, liquids, and nasals. All short vowels had been acquired at the age of 2;3 years, earlier than most long vowels, the reduced vowel /ə/, and the diphthong /ɑu/.

The order of acquisition in which consonants were learned is broadly comparable with what Beers (1995) described, provided that in her study all syllable-initial consonants were acquired before the age of 3;0 years. Curiously, she does not mention the age of acquisition of the consonants /v/ and /z/ . We found that, in syllable-initial position, these two consonants were not acquired until 4;3 years of age (4;4 and 5;4 years, respectively). The difference in the age of acquisition Beers and we recorded may be due to the different methods of speech elicitation that were used. In her 1995 study, Beers analyzed spontaneous speech samples, which, as alluded to above, carries the risk that children avoid phonetic contexts that they have (more) difficulty with, 'choosing' the consonants that they can produce more easily and accurately. As the picture-naming task we used includes all Dutch phonemes, the children in our sample were made to produce a wider range of consonants, which inevitably elicits less accurate utterances. Note that the acquisition criterion is based on the proportion of correct productions, not on the total number of productions. This avoidance of difficult phonemes in spontaneous speech may then also be one of the explanations why Beers does not report on the production of /v/ and /z/. Alternatively or additionally, dialect variation may have played a role. In the Western part of the Netherlands the voiced consonants /v/ and /z/ are often pronounced as the voiceless consonants /f/ and /s/ and the children in the study of Beers (1995) all lived in the Central Western part of the Netherlands, where voiced fricatives tend to be devoiced. The children we tested resided in all four regions of our country, making our sample more representative of the general Dutch population in terms of geographic range.

Degrees of complexity

As to the distinctive features in typical Dutch speech sound development, our results pertaining to the degrees of complexity broadly confirmed the order of acquisition Beers (1995) had observed, with the exception of the 'dorsal' contrast, which in our study was acquired after the 'continuant' contrast. We noted that all contrasts were produced correctly at 3;8 years of age, whereas Beers (1995) concluded that most were mastered at the younger age of 2;9 years. Again, this disparity in the age of acquisition may be due to Beers' use of spontaneous speech rather than a naming task, with the children in her study possibly selecting the consonants in contexts that they were most comfortable with, while we confronted the children in our sample with a fixed set of words in varying contexts.

Syllable structure inventory

All syllable structures were acquired at the age of 4;7 years, except for the CCVCC sequence, which had not yet been acquired at 6;11 years of age. The simple structures, such as CV, CVC, and V were established first, followed by the syllables with an initial or final consonant cluster of two consonants (CCV, CCVC, CVCC), with those with an initial consonant cluster of three consonants (CCCVC) being acquired last. Syllable structures with initial clusters were established before those with final clusters, which closely resembles the order of acquisition reported in previous studies on the acquisition of Dutch (Van den Berg et al., 2017, Fikkert, 1994, Levelt et al., 2000) and other languages (Gangji et al., 2015, Mahura and Pascoe, 2016).

Phonological processes

As expected, we observed more phonological simplification processes in the children in the younger age groups. By the age of 4;4 years, all simplification processes had disappeared, except for the initial cluster reduction from three to two consonants (14.3%) and the final cluster reduction from two to one consonant (44.5%). These results are consistent with Dodd et al. (2003), who reported that in English-speaking children most phonological processes were resolved by 4;0 years and comparable with the findings in other languages (Clausen and Fox-Boyer, 2017; Pascoe et al., 2018). In our study, of all phonological processes, cluster reduction was present the longest, which, again, is in line with other studies in other languages (Aalto et al., 2019; Pascoe et al., 2018).

Besides simplification processes, we studied the use of unusual phonological processes, systematic speech errors that do not usually occur during typical development and are considered to indicate deviant development. Most of the unusual processes Beers (1995) had noted in her sample of typically developing children (i.e. backing, nasalization, H-sation, and lateralization) did not occur in our sample. We did, however, observe stopping of non-fricatives, denasalization, and dentalization in a small number of children in the youngest age groups (up to the age of 3;0 years).

Surprisingly, we found no evidence of ‘gliding’. Beers (1995) described this substitution process as one of the most frequently occurring phonological processes in typically developing Dutch-speaking children, which is commonly used until the age of 4;0 years, similar to trends found in other languages like British English and South-African English (Dodd et al., 2003; Pascoe et al., 2018). Gliding occurs when the liquids /l/ and /r/ are replaced by the glides /j/ or /w/. In our data, the /l/ and /r/ are two of the latest consonants acquired, that is, not until the ages of 3;7 and 4;7, respectively. The glides /j/ and /w/ are acquired at a far younger age, i.e. at age 2;7 and 2;11 years, respectively. Possibly, the children in our study omitted these consonants more than they substituted them.

Limitations

In order to be able to compare narrow age ranges (14 age groups), we needed as large a sample as possible (*n* = 1,503), which is why we opted for a cross-sectional design. For most sounds, a monotonous increase in accuracy with age was found, confirming the reliability and validity of accuracy as an indicator of speech development, with only minor discontinuities of just a few percentage points occurring for most sounds. We chose to define the age of acquisition as the first age category at which 75% of the children produced a sound correctly 75% of the time. For two sounds, the /x/ and the /r/, these discontinuities led to uncertainty in determining the age of acquisition. For example, applying the 75% criterion consistently, the syllable initial consonant /x/ was found to have been acquired at age 3;0-3;3, but not in the 3;4-3;7 age group, and then again in the children aged 3;8-3;11 years. With the /r/ sound, the score of the 5;0-5;3-year-olds posed a problem, being substantially below 75%, whereas two younger age-groups scored well above this threshold. We hence chose to take the youngest age category in which the 75% criterion was reached as our reference for the classification of typical development in such cases, thereby taking into account the possible variability in speech production during a transitional period as Sosa (2015) suggested.

Young children with typically developing speech show sometimes distortions of sounds (Shriberg et al., 1997) that reflect an imprecise production of targeted sounds (e.g. dentalization or lateralization of the /s/, or labialization of the /r/) but with a correct phoneme selection. However, in words or in context, it cannot be distinguished whether distortions are of a phonetic or a phonological origin (Namasivayam et al., 2020). Despite providing a detailed description of speech sound development, we did not record systematic distortions (e.g. lisps). The distortion (e.g. the lisp) itself cannot be diagnosed with the CAI. However, with respect to all other aspects of speech sound development a child with a lisp can be compared to the norms. Our norms are suitable for these children, but not for diagnosing the distortion per se. ~~rendering our norms unsuitable to identify children with isolated articulation distortions.~~ In ongoing and planned research of the CAI software, we will focus on the development of rules to support the analysis of sound-by-sound contextual speech error patterns in word naming and conversational or spontaneous speech.

A final limitation we need to mention is that all results were based on analyses at the syllable level, which, among other restrictions, implies that weak syllable deletion was not considered. Possible effects of word length – expressed as the number of syllables – could therefore not be assessed. Since previous studies did report word-length effects, finding that children's speech production was less accurate for long words than it was for short words (Gangji et al., 2015, Maphalala et al., 2014, Vance et al., 2005), we will be adding word length and word structure as features for analysis to the next version of the CAI.

Clinical implications

No previous studies reported PCC-R and PVC for typically developing Dutch-speaking children despite the fact that these measures are widely used to support the diagnosis of SSDs (McLeod and Crowe, 2018), where PCC-R is most relevant to determine the severity of involvement (Shriberg et al., 1997).

Providing normative data obtained in 1,503 typically developing Dutch-speaking children, our inventory may be of use to SLPs who work with children suspected of an SSD. The norm scores were derived from the items of the picture-naming task of the CAI (Maassen et al., 2019), whose psychometric properties were verified, with our earlier studies revealing sufficient interrater reliability, test-retest reliability, and construct validity (Van Haaften et al., 2019a), and supported known-group validity (Van Haaften et al., 2019b). The CAI has since been made available for use in Dutch clinical practice. Describing typical speech sound development in terms of PCC-R and PVC, consonant, vowel, and syllabic structure inventories, degrees of complexity (phonemic feature hierarchy), and phonological processes, our assessment provides Dutch SLPs with a baseline against which the speech of children can be compared to determine the presence of an SSD. Based on the normative data on typically occurring phonological processes, clinicians can determine whether a child's speech development is comparable to that of age peers or whether it is delayed or impaired. The picture-naming task of the CAI is a practical and efficient means to gain detailed information about a child's production of speech sounds with the norm scores aiding the decision whether a child is in need of speech language therapy services.

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Appendix A

The words elicited in the picture-naming task of the Computer Articulation Instrument (CAI)

No.	Item (*English translation*)	IPA transcription	No.	Item (*English translation*)	IPA transcription
1	auto *(car)*	/ɑu-to/	31	strik *(bow)*	/strɪk/
2	bal *(ball)*	/bɑl/	32	snoepje *(candy)*	/snup/
3	bloem *(flower)*	/blum/	33	trein *(train)*	/trɛin/
4	fiets *(bicycle)*	/fits/	34	vis *(fish)*	/vɪs/
5	stuur *(steering wheel)*	/styr/	35	water *(water)*	/wa-tər/
6	wiel *(wheel)*	/wil/	36	bus *(bus)*	/bʉs/
7	flesje *(bottle)*	/flɛʃ-ʃə/	37	wip *(seesaw)*	/wɪp/
8	fluit *(flute)*	/flʉyt/	38	zeep *(soap)*	/zep/
9	gieter *(watering can)*	/xi-tər/	39	zon *(sun)*	/zɔn/
10	nat *(wet)*	/nɑt/	40	klok *(clock)*	/klɔk/
11	haan *(rooster)*	/han/	41	lepel *(spoon)*	/le-pəl/
12	kip *(chicken)*	/kɪp/	42	mes *(knife)*	/mɛs/
13	huis *(house)*	/hʉys/	43	pop *(doll)*	/pɔp/
14	deur *(door)*	/dør/	44	ring *(ring)*	/rɪŋ/
15	raam *(window)*	/ram/	45	spin *(spider)*	/spɪn/
16	meisje *(girl)*	/mɛiʃ-ʃə/	46	televisie *(television)*	/te-lə-vi-si/
17	broek *(pants)*	/bruk/	47	knoop *(button)*	/knop/
18	jongen *(boy)*	/jɔŋ-ŋən/	48	man *(man)*	/mɑn/
19	jas *(coat)*	/jɑs/	49	lamp *(lamp)*	/lɑmp/
20	springtouw *(jump rope)*	/sprɪŋ-tɑuw/	50	dak *(roof)*	/dɑk/
21	jurk *(dress)*	/jʉr-rək/	51	gordijn *(curtain)*	/xɔr-dɛin/
22	sleutel *(key)*	/slø-təl/	52	giraf *(giraffe)*	/ʒi-rɑf/
23	schaar *(scissors)*	/sxar/	53	vrachtwagen *(truck)*	/vrɑxt-wa-xən/
24	sok *(sock)*	/sɔk/	54	kleurpotlood *(crayon)*	/klør-pɔt-lot/
25	speld *(pin)*	/spɛlt/	55	olifant *(elephant)*	/o-li-fɑnt/
26	neus *(nose)*	/nøs/	56	kapstok *(coat rack)*	/kɑp-stɔk/
27	tong *(tongue)*	/tɔŋ/	57	vliegtuig *(airplane)*	/vlix-tʉyx/
28	kast *(closet)*	/kɑst/	58	viltstift *(felt-tip pen)*	/vɪlt-stɪft/
29	stoel *(chair)*	/stul/	59	paraplu *(umbrella)*	/pa-ra-ply/
30	strijkijzer *(iron)*	/strɛik-ɛi-zər/	60	telefoon *(telephone)*	/te-lə-fon/

Appendix B

Frequency distributions of the phonological features in the picture-naming task

Class	Feature	Number of syllable-initial features
Consonants	p	4
	b	2
	t	9
	d	3
	k	3
	g	-
	ŋ	-
	m	3
	n	2
	l	6
	r	4
	f	6
	v	3
	s	5
	z	3
	ʃ	2
	ʒ	1
	j	3
	x	3
	h	2
	ʋ	4
Vowels	i	8
	y	2
	e	4
	ø	4
	a	7
	o	5
	u	4
	ɪ	9
	ɛ	3
	ɑ	11
	ʉ	2
	ə	12
	ɔ	9
Diphthongs	ɛi	5
	ɑu	2
	ʉy	3
Syllable structures	V	3
	CV	17
	VC	-
	CVC	40
	CCV	3
	CVCC	6
	CCVC	15
	CCVCC	3
	CCCVC	3
Initial consonant clusters	/vl-/, /vr-/, /fl-/, /bl-/, /br-/, /pl-/, /tr-/, /kl-/, /kn-/, /sn-/, /sp-/, /st-/, /sx-/, /sl-/, /spr-/, /str-/	
Final consonant clusters	/-ft/, /-xt/, /-lt/, /-mp/, /-nt/, /-rk/, /-ts/, /-st/	

Table 1. The consonants of Dutch

Place of articulation	**Manner of articulation**				
	Plosives	Fricatives	Nasals	Liquids	Glides
Bilabial	p, b		m		
Labiodental		f, v			w
Alveolar	t, d	s, z	n	l, r~~ʀ~~	
Post alveolar	(c)	(ʃ), (ʒ)	(ɲ)		
Palatal					j
Velar	k, (g)	x	ŋ		
Glottal		h			

Note. Four additional consonants are presented in parentheses because they only occur in loanwords and/or as allophones

Table 2. Degrees of Complexity of phonological contrasts of Dutch syllable-initial consonants described by Beers (1995)

Degree of Complexity	Contrastive feature	Segments
Degree 1	Sonorant, labial, coronal	/p/, /t/, /m/, /j/, /n/
Degree 2	Dorsal	/k/
Degree 3	Continuant	/s/, /x/, /h/
Degree 4	Front, round	/b/, /f/, /w/
Degree 5	Lateral, rhotic, nasal	/l/, /r~~ʀ~~/

Table 3. Age and gender for the 14 age groups of the study population

Age group (years;months)	Mean age (years;months)	Girls *(n)*	Boys *(n)*	Total *(n)*
2;0-2;3	2;1	42	30	72
2;4-2;7	2;5	46	55	101
2;8-2;11	2;10	55	46	101
3;0-3;3	3;1	51	51	102
3;4-3;7	3;6	46	61	107
3;8-3;11	3;9	45	56	101
4;0-4;3	4;2	45	54	99
4;4-4;7	4;5	53	58	111
4;8-4;11	4;10	57	55	112
5;0-5;3	5;2	53	64	117
5;4-5;7	5;5	57	71	128
5;8-5;11	5;10	52	64	116
6;0-6;5	6;2	48	69	117
6;6-6;11	6;9	62	57	119
Total		712	791	1503

Table 4. Percentage of consonants correct-revised and percentage of vowels correct by age group

Age group (years;month)	*n*	PCC-R	*SD*	PVC	*SD*
2;0-2;3	72	76.3	12.8	87.5	9.71
2;4-2;7	101	80.9	12.8	89.2	8.10
2;8-2;11	101	89.0	7.38	93.3	4.96
3;0-3;3	102	91.5	6.05	95.1	4.15
3;4-3;7	107	91.7	5.71	95.3	3.83
3;8-3;11	101	92.6	5.48	96.5	3.49
4;0-4;3	99	94.5	5.25	96.8	4.13
4;4-4;7	111	96.0	3.18	97.7	2.87
4;8-4;11	112	96.2	2.85	98.0	2.24
5;0-5;3	117	95.7	3.91	97.7	3.09
5;4-5;7	128	96.3	5.19	97.6	5.52
5;8-5;11	116	97.3	3.05	98.5	2.41
6;0-6;5	117	97.1	3.01	98.4	2.33
6;6-6;11	119	97.6	2.19	98.6	1.78

Note. PCC-R = Percentage of consonants correct-revised; PVC = Percentage of vowels correct

Table 5. Phonetic~~me~~ inventory (≥75% of the children produce the sound correctly)

Age group	*n*	Consonants										Vowels			
		Syllable initial					Syllable final								
		Plosives	Fricatives	Nasals	Liquids	Glides	Plosives	Fricatives	Nasals	Liquids	Glides	Short	Long	Reduced	Diphthongs
2;0-2;3	72	/b, t/		/m, n/				/f, s/	/m/	/l/		/ɪ, ɛ, ɔ, ʉ, ɑ/	/y, u, o, a/		/ʉy, ɛɪ/
2;4-2;7	101		/s/			/j/	/p/				/w/		/i, ø/		
2;8-2;11	101	/p, d, k/	/f, ʃ, h/			/w/	/t, k/	/ʃ/	/n/					/ə/	/ɑu/
3;0-3;3	102		/ʒ, x/										/e/		
3;4-3;7	107				/l/			/x/							
3;8-3;11	101									/ɾʀ/					
4;0-4;3	99								/ŋ/						
4;4-4;7	111		/v/		/ɾʀ/										
4;8-4;11	112														
5;0-5;3	117														
5;4-5;7	128		/z/												
5;8-5;11	116														
6;0-6;5	117														
6;6-6;11	119														

Table 6. Percentages of children per age group who acquired the degrees of complexity

Degrees of Complexity	**Segments**	**Age groups**													
		2;0-2;3	2;4-2;7	2;8-2;11	3;0-3;3	3;4-3;7	3;8-3;11	4;0-4;3	4;4-4;7	4;8-4;11	5;0-5;3	5;4-5;7	5;8-5;11	6;0-6;5	6;6-6;11
Degree 1	/p/, /t/, /m/, /j/, /n/	83.3	86.1	99.0	99.0	99.1	100	100	100	100	100	100	100	100	100
Degree 2	/k/	50.0	64.9	82.0	87.1	87.6	94.0	94.9	96.4	100	97.4	97.7	99.1	98.3	99.2
Degree 3	/s/, /x/, /h/	62.0	80.0	93.1	94.1	96.3	99.0	96.0	100	99.1	98.3	96.9	99.1	100	100
Degree 4	/b/, /f/, /w/	63.9	74.0	83.2	91.1	93.5	97.0	97.0	99.1	99.1	100	98.4	100	100	100
Degree 5	/l/, /r~~ʀ~~/	20.0	32.7	48.0	60.0	70.1	79.0	88.9	86.5	94.6	92.3	95.3	96.6	99.1	99.2

Note. Grey cells indicate that a degree is acquired in an age group; the syllable-initial consonants of a degree were produced ≥ 75% correct on average by at least 75% of the children

Table 7. Syllable structure inventory (>75% of the children produce the syllable structure correctly)

Age group (years;month)	**Correctly produced syllable structures (75% criterion)**
2;0-2;3	CV, CVC
2;4-2;7	
2;8-2;11	V
3;0-3;3	CCV, CCVC
3;4-3;7	
3;8-3;11	CVCC
4;0-4;3	
4;4-4;7	CCCVC
4;8-4;11	
5;0-5;3	
5;4-5;7	
5;8-5;11	
6;0-6;5	
6;6-6;11	
>7;0	CCVCC

Table 8. Percentages of children per age group who use the phonological processes at least 10%

Phonological processes	**Age groups**													
	2;0-2;3	2;4-2;7	2;8-2;11	3;0-3;3	3;4-3;7	3;8-3;11	4;0-4;3	4;4-4;7	4;8-4;11	5;0-5;3	5;4-5;7	5;8-5;11	6;0-6;5	6;6-6;11
Simplification processes														
Fronting	47.9	34.0	37.6	19.8	24.3	10.9	7.1	7.2	2.7	7.7	0.8	2.6	1.7	0.0
Stopping of fricatives	35.2	13.9	9.9	4.0	1.9	4.0	2.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0
Voicing	6.9	3.0	1.0	0.0	0.9	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0
Devoicing	45.8	32.0	18.8	8.9	10.3	14.9	11.1	4.5	8.0	6.0	2.3	3.4	3.4	0.8
Gliding	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clusred 2to1 ini	90.0	75.5	51.0	37.0	29.2	19.8	11.1	8.1	4.5	9.4	7.0	2.6	0.9	0.0
Clusred 3to1 ini	60.9	38.2	24.2	9.2	12.4	9.1	1.0	0.9	2.7	2.6	2.4	2.6	1.7	0.8
Clusred 3to2 ini	57.8	59.6	61.1	38.8	40.0	32.3	26.8	13.6	19.6	17.9	11.0	9.5	11.2	14.3
Clusred 2to1 final	94.1	86.7	78.6	73.0	70.8	71.3	51.5	52.3	52.7	53.8	41.4	38.8	39.3	44.5
Unusual processes														
Backing	4.2	6.9	1.0	1.0	0.9	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unusual stopping	16.9	9.0	2.0	1.0	0.0	1.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0
Nasalisation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Denasalisation	14.1	14.1	6.9	6.9	0.9	2.0	2.0	0.9	3.6	1.7	1.6	0.9	1.7	0.0
Hsation	2.8	3.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dentalisation	19.4	11.9	13.9	5.9	3.7	3.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lateralisation	1.4	0.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Note. Grey cells indicate the process is present in the particular age group, that is, reaches the criterion of at least 10% occurrence in at least 10% of the participants; Clusred = cluster reduction